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by:

W. C. Erickson

M. M. Komesaroff

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

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INSTITUTION: Department of Physics and Astronomy
University of Maryland
College Park, Maryland

PRINCIPAL INVESTIGATORS: William C. Erickson
Max M. Komesaroff

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PURPOSE OF THIS GRANT:

One of the primary purposes of this grant was to enable Professor Komesaroff to join the University of Maryland faculty and to contribute his valuable experience and knowledge of long wavelength radio astronomy to a rational program of ground-based and space borne observations. He and Dr. Erickson have been considering the various aims of possible observing programs at the long wavelength end of the radio spectrum, their scientific importance, and the feasibility of accomplishing them either from the earth's surface or from a space platform.

In order to assess the feasibility of various programs, we need practical experience in high resolution observations. To gain this experience, grant funds have been used to extend the array at Clark Lake to a 4 mile baseline. This will yield a 4' beamwidth and will indicate whether or not arrays of such aperture are practical on the earth's surface.

Another purpose of this grant was to solidify the interaction between the radio astronomy group at the University of Maryland and the radio astronomy section at the Goddard Space Flight Center. This interaction has been cordial and mutually beneficial. The Goddard staff have made use of the observing facilities at the University of Maryland's Clark Lake Radio Observatory, we have cooperated in analysis and interpretation of Clark Lake data, and have frequently shared equipment, techniques, and "know-how". We hope that our participation will prove beneficial to the radio astronomy satellite program, and that this working relationship will continue in the interpretation of satellite data.

THE AIMS OF LONG WAVELENGTH OBSERVATIONS:

We will begin this report with a discussion of the various scientific problems which might be attacked at long wavelengths; we will outline their requirements and the feasibility of successfully satisfying these requirements.

SOLAR WORK:

The determination of the brightness distribution of the quiet sun at various wavelengths would yield some interesting data concerning the variation of electron temperature and density in the corona, but the interpretation of such observations is not straightforward. Moderately high resolution of 5' to 10' would be required as well as high sensitivity. Although such data would be useful, they do not alone provide sufficient justification for the effort involved in building an array to obtain them. Such observations have been made at 7.9m (P. A. O'Brien, M.N.R.A.S., 113, 597 (1953)), and at 11.4m (W. M. Cronyn, MA Thesis, U. of Md. - in preparation). At longer wavelengths, the apparent brightness temperature of the corona decreases and its contrast against the galactic background weakens. The galactic reflections predicted by Bracewell and Preston (Ap.J., 123, 14, (1956)) have not been observed.

A study of active solar emission would be more rewarding. J. P. Wild in Australia is constructing an array to yield a two-dimensional "picture" of the sun with high time resolution at 1.5m wavelength. A similar instrument operating at decameter wavelengths would trace solar emission regions far out in the corona. Such a device, operating at solar maximum, should yield very exciting results. It appears to be practical, and relatively inexpensive since the large collecting areas, necessitated by the requirement of high time resolution and short integration times, can be obtained cheaply. It is difficult to estimate the angular resolution required for such works. Most solar emission regions are resolved by the 10' beamwidth of the Clark Lake instrument, but on at least one occasion we have observed smaller structures (W. C. Erickson, J.G.R., 66, 1773, (1961)). No doubt, angular resolution in the 5' to 10' range coupled with time resolution of about 1 sec. would provide interesting data concerning the propagation of solar disturbances through the corona. The instrument must be capable of following the sun for 2 to 3 hours either side of the local meridian and must be capable of scanning or synthesizing the two dimensional solar brightness distribution. A reasonable goal might be to construct an instrument that would detect solar sources of about 10^{-23} w/m^2 cps flux. This would make the instrument somewhat more sensitive than existing swept-frequency receivers.

At present, spectral observations of the sun extend over nearly all of the frequencies observable from the earth's surface. The diurnal coverage is far from complete, but this could be rectified by duplication of existing instruments. In the decimeter range, greater time resolution may be profitable. In the decameter range, greater sensitivity might possibly be useful since there is a large gap between the sensitivity of present instruments and the emission from the undisturbed sun. However, Clark Lake observations at 11.4m which bridge this gap yield no indication of new phenomena in this region. Therefore, an increase in the sensitivity of decametric spectral receivers is probably not of first order importance. Thus it appears that the most interesting spectral observations are to be made from satellites at frequencies outside of the atmospheric pass-band. In particular, spectral observations should be conducted during the next solar maximum which would follow up the preliminary swept-frequency observations made from the Goddard radio astronomy satellite.

PLANETARY WORK:

Jupiter is the only positively identified planetary radio source at decametric wavelengths. Scattered reports of decametric emission from other planets have not been confirmed (T. D. Carr, et al, Ap.J., 134, 105, (1961) P. Brissinden and W. C. Erickson, Ap.J., 136, 1140, (1962)). The study of the intense bursts at several decametric wavelengths is already being actively pursued through the Goddard-Yale project which is erecting a chain of Jupiter observing stations at various longitudes. This will yield nearly full time coverage of Jupiter's emission. There is also low-level emission with characteristics similar to those of the strong emissions (R. G. Stone, J. K. Alexander, and W. C. Erickson, Ap.J., 140, 374, (1964)). It would be interesting to study these low-level emission further, and also to detect the decametric end of the decimeter emission spectrum. In addition, further attempts should be made to detect sporadic emission from other planets.

Pioneering work on the angular distribution of Jupiter's decametric source has been carried out by Slee and Higgins (Nature, 197, 782, (1963)). Through use of very long baseline interferometers, they have resolved the source at a wavelength of 19.7m. Currently, they are operating with a 100km baseline. Their work has shown that two rays may remain coherent even though they traverse the ionosphere at very widely separated points. However, measurements such as these are necessarily crude and difficult and it is not clear that further work would be very profitable.

RADAR WORK:

One of the most promising fields of study in coronal physics is soft target radar work. Solar echoes have been detected and have already yielded interesting data. Much will be learned with more advanced equipment. We are not proposing, however, to build a large transmitter, but the type of antenna which we may construct would be an excellent receiving element for a bistatic radar system.

CORONAL TRANSMISSION WORK:

The scattering of radio waves in the solar corona has been observed by a number of investigators (Hewish and Wyndham M.N.R.A.S., 126, 469, (1963) W. C. Erickson Ap.J., 139, 1290, (1964)). Most of these measurements have involved radiation from only one source, Tau A, which is occulated by the solar corona in mid-June each year. Thus we obtain data concerning only a restricted strip of the corona. However, Slee (M.N.R.A.S., 123, 223, (1961)) has pioneered work using a number of sources to obtain the shape of the corona in more detail. With a highly sensitive array, it would be most interesting to extend these measurements to a very large number of sources, map the shape of the corona in detail, and correlate these data with satellite chromograph observations. Hewish, Scotts, and Willis (Nature, 203, 1214, (1964)) have recently observed interplanetary scintillations of small angular diameter radio sources. There are reasons to believe that these scintillations will not occur at decameter wavelengths except in the case of exceedingly small angular diameter sources ($\simeq$ 1" diameter), but if these scintillations could be observed, they would yield data concerning very fine angular structure in radio sources, as well as the average distance to the interplanetary scattering regions. To observe these scintillations a highly sensitive array capable of resolving sources to a level of about 1 flux unit (10^{-26} w/m^2 - cps) and with the capability of following a source in hour angle would be required.

The use of a decametric array in a receiving system to observe signals from a space probe in a solar orbit has been considered.

Although transmission effects through the solar corona would be larger at decameter wavelengths than at meter wavelengths, they are easily measurable at meter wavelengths. Considering the high noise levels at decameter wavelengths due to galactic background radiation, the use of these wavelengths is not indicated.

OBSERVATIONS OF FLARE STARS:

It has now become fairly well established that U V Ceti variables emit radio waves (B. Lovell and B. F. Chugainov Nature, 203, 1213, (1964)) of measurable intensities. A sensitive decametric antenna would be most useful in the further exploration of these and other similar phenomena.

GALACTIC WORK:

An array with a collecting area of some thousands of dipoles and having a primary beamwidth of 15' arc or better at decametric wavelengths would permit the investigation of a number of problems related to the structure and evolution of the Galaxy.

The deep absorption minimum along the galactic plane found in earlier work (C. A. Shain, Aust. J. Phys., 10, 195, (1957); C. A. Shain, M. M. Komesaroff, and C. S. Higgins, Aust. J. Phys., 14, 508, (1961)) could be studied in considerable detail and should yield considerable information about the large-scale distribution of galactic ionized hydrogen. In addition, rough estimates could be made of distances to individual H II regions, as well as the non-thermal emission per unit volume in various parts of the Galaxy.

GALACTIC SOURCES:

Many or all of the galactic sources seen in emission at decametric wavelengths are super nova remnants, believed to be an important source of cosmic rays and heavy nuclei. Decametric studies of fluxes and brightness distributions, in conjuction with shorter wavelength data can provide information about the distances and ages of these objects as well as giving some indication of their contribution to the "background" non-thermal emission from the whole Galaxy.

EXTRAGALACTIC SOURCES:

It would be useful to obtain decametric flux measurements on a large number of extragalactic sources. Williams (Nature, 200, 56, (1963)) has shown that the spectra of high brightness temperature sources curve downward at decametric wavelengths. This bend in the spectrum is the only outstanding feature yet found in the relatively featureless spectra of most sources. If the curvature is caused by synchrotron self-absorption, and if the flux and angular size of the source can be determined, we can estimate the average electron energies and magnetic field intensities in sources. This would be a great step forward in our physical understanding of these objects, and should be a goal of first importance.

The accomplishment of this goal imposes stringent instrumental requirements. Radio source fluxes can be obtained with moderate instruments. At Clark Lake we are in the process of determining the fluxes of about 400 sources at 26 mc/s. A similar number of sources are being observed by Cambridge University at 38 mc/s. However, we must also estimate the angular sizes of small, high brightness temperature sources. Since these angular sizes are 10" or less, we must utilize lunar occultation or very long (100-1000 mile) baseline interferometers. In either case, we must have sufficient collecting area and resoltuion to obtain a large signal-to-noise ratio on these relatively weak sources. This would require collecting areas of at least 20,000m^2 and beam areas of less than 0.1 square degrees. Both the lunar occultation and long baseline interferometer method of attacking this most important problem should be developed. If this cannot be done from the earth's surface, then it should certainly be done from space vehicles.

SUMMARY:

It appears to be a reasonable goal to construct one or more high resoltuion arrays for ground based observations of discrete sources, the sun, and the Galaxy. These observations should employ the maximum resolution attainable beneath the ionosphere and the instrument for discrete source work should have adequate sensitivity to be resolution-limited. This class of instrument would obviously have many other applications.

We should also pursue methods of obtaining extremely high resolution for the study of the structure of high brightness temperature sources either through lunar occultations, long baseline interferometers, or space vehicles.

Last, but not least, a swept frequency receiving system above the ionosphere for solar observations below 10mc/sec is imperative.

WORK CARRIED OUT UNDER THE GRANT:

1) A large fraction of the funds provided by this grant were expended on salaries. In particular, this enables one of us to participate in the program, and in the formulation of the aims outlined above.

2) Professor Komesaroff devoted a fraction of his time to the analysis of data which he brought from Australia. Some computer time and student assistant time has also been devoted to this.

Analysis has been completed of a 408 mc/s survey of the Galaxy between l II = 285° and 355° and between b II = $\pm 6°$, undertaken with the CSIRO 210 foot telescope at Parkes, N. S. W., Australia. The beamwidth at this frequency is about 47' arc, permitting useful comparisons with earlier surveys of similar resolution by Hill, Slee, and Mills (1958) and Mathewson, Healy, and Rome (1962) at 85 mc/s and 1440 mc/s respectively.

Forty-nine discrete sources were detected, and for the majority spectral indices could be estimated by comparison with the earlier surveys. A few seems to exhibit spectral curvature too large to be attributed to experimental error, and these should warrant further investigation. Perhaps the most interesting result related to the "step" in the background radiation near l II = 326°, symetrical in longitude with a "step" in the thermal component of emission observed by Westerhout in the Northern Hemisphere. This non-thermal feature has no counterpart of comparable magnitude in the Northern Hemisphere and therefore seems to represent a large-scale asymmetry in the Galaxy.

3) We have made preliminary specification of an antenna fulfilling the requirements for the discrete source, galactic, and solar studies outlined above. Considerable time and effort has been spent in the design of very simple receiving and phase shifting elements. Since about 1000 of these elements would be required in the array that we contemplate, we must have a clever design which combines simplicity with reliability. Our requirements are similar to those of any future array which may be erected in space, and this engineering work should prove useful in that environment also.

We are not yet prepared to give a detailed technical discussion of the antenna and its components. However, it is apparent that we need the gain of a few thousand dipoles, and a beamwidth of at most 15' in each direction. If it is practical to employ higher resolution than this from the earth's surface, we will wish to do so. It is also of paramount importance that the phasing of the N-S arm of the antenna be controllable from the central point.

At a later time, we will discuss the methods by which we propose to do this.

4) In order to help evaluate the practical limitations on the

resolution of decametric arrays, we have built extensions to the Clark Lake antenna. These extensions consist of four elements along a 2 mile baseline off the eastern end of the present antenna. With these extensions, we will obtain one-dimensional resolutions of 4'. Since the collecting area of the newly built extension is only a factor of two less than that of the present spaced array, we should obtain sufficient resolution to observe a number of galactic and extragalactic sources, as well as the sun. We plan to use this antenna to investigate small angular diameter structure of discrete sources. Some evidence for the existence of such structure has been reported by the Cambridge group (B. H. Andrew, N. J. B. A. Branson, D. Willis, Nature, 203, 171, (1964)). The antenna will also be very useful for solar research.

At present, the extension elements have been completed. They have yet to be adjusted and placed in operation. This will be done as soon as time permits.

5) Since we are now considering a new antenna extending over several miles aperture, the possible configurations for the arrays are strongly influenced, and often governed, by the site which is available. Such an antenna cannot be designed independently of the topography of the land. Almost any alteration of the topography over these dimensions involves moving of millions of tons of earth, and the expenses which are orders of magnitude greater than that of the instrument itself. Therefore, considerations of possible sites and their relative merits must come into the initial planning of the instrument.

We have undertaken a rather exhaustive survey of possible sites and we believe that we have considered every appropriate site in the United States. We have monitored terrestrial interference and have investigated the availability of the land for the most appropriate ones. Since these data are useful to groups at several other universities who are planning large decametric or micro-wave antennas, we are preparing a complete report concerning these sites. We plan to circulate this report to other interested groups. Eventually it may be possible for several groups to share a large site, and alleviate the cost of site procurement and development, and of living and laboratory accomodations.